# Evaluating the Performance of Alternative Municipal Water Tariff Designs: Quantifying the Trade-offs between Equity, Economic Efficiency, and Cost Recovery

October 11, 2016

Céline Nauges and Dale Whittington

## Introduction

There are many reasons to get water prices right. Increasing water scarcity and climate change now need to be added to the list. Climate change in particular presents water and wastewater utilities with a complex new set of management and strategic challenges. One important way for water utilities to deal with the uncertainty introduced by climate change is to maintain cash reserves that can be deployed to address problems as they arise. But few water utilities generate sufficient cash to cover their full costs, and typically are unable to invest to protect strategic capital assets from extreme events or to build new capital facilities to address changes in rainfall and streamflow variability.

It is thus increasingly important for water utilities to adopt financially and economically sound water tariff designs that enable them to reliably provide essential services to their customers. This requires that water utilities have access to the expertise to understand how tariff reforms will affect water use, revenues, and capital investment needs, and how these in turn affect the multiple criteria that are used to assess the performance of water tariffs. This capability to carefully model the full array of consequences of a tariff reform process is currently not well developed in either water utilities themselves or in the community of consultants who support them.

In this paper we build upon and modify a simulation model first used by Whittington et al. (2015) to assess how subsidies are distributed across households under an existing increasing block tariff (IBT) structure. In this paper we expand upon our prior analysis to examine the consequences of a change from an existing uniform volumetric price (UP) tariff structure to an IBT, and to estimate how this tariff reform would affect three objectives: equity, economic efficiency, and cost recovery. Our purpose is to develop a better understanding of the trade-offs between these three objectives for different water tariffs. It is widely recognized that the design of municipal water tariffs requires balancing multiple objectives such as financial self-sufficiency for the service provider, equity (especially for poor households), and economic efficiency for society. However, the actual trade-offs between these competing objectives are rarely quantified for policy makers. As a result policy makers typically do not have a clear picture of the choices they face. They are thus forced to rely on their intuition to judge these trade-offs.

As in Whittington et al. (2015), we rely on hypothetical (simulated) data for a population of 5000 households, and assume that water use and income across the population can be best represented by log-normal distribution functions. We use simulated data instead of real data for three reasons. First, household data sets that combine accurate information on household water use and monthly water bills with information on household income are rare (Whittington et al., 2015). Second, the large number of datasets and studies on residential water demand around the world, as well as numerous income studies, provide sufficient information to calibrate distributions of water use and income among a hypothetical population of households connected to the piped water distribution system. Third, simulated data allow us to study a range of IBTs designs and to check how their performance in terms of equity and economic efficiency is affected by characteristics of the IBT, including the size of i) a positive, fixed charge, ii) the first (lifeline) block, and iii) the price in different blocks.

We do not claim to identify a tariff structure that finds the optimal balance between the three objectives that are the focus of this paper (cost recovery, equity, and economic efficiency).[1] Rather we analyze how the shift from a UP tariff to different IBTs designs affects households' water use and water bills, and how these changes in turn affect measures of equity and economic efficiency for different cost recovery constraints.

The analysis of a shift from a UP tariff to an IBT necessitated making assumptions about how households would respond to changes in prices (i.e., households' price elasticity of demand), which is an important difference compared to the analysis in Whittington et al. (2015). We also make assumptions about the costs of services, household income, and household water use that are similar to many cities in industrialized countries. Our analysis is also applicable to cities in developing countries where households have metered, piped connections, but assumptions about the magnitude of some parameters such as household income and costs of services would need to be adjusted to more closely reflect local conditions.

We model a shift to an IBT because IBTs are currently the most popular tariff structure used by water and wastewater utilities globally.[2] A common argument in favor of IBTs is that charging large water users a higher volumetric price (in higher blocks) allows utilities to provide a minimum quantity of water to some households at a reduced volumetric price in the lower, "lifeline" block. Households that benefit most from this reduced volumetric price use small amounts of water, and are commonly thought to be the poorest. However, for this cross-subsidization from the rich to poor households to happen, two conditions are necessary. First, low-income households should consume less water than high-income households. Second, the volumetric price that is charged in the higher blocks should be above average cost. If all the volumetric prices in the IBT structure (from the lowest to the highest block) are below average cost, then all units of water, whether sold to small or large users, will be subsidized. As a consequence, those who consume more water will receive more subsidies, a situation that is inconsistent with the objective of targeting subsidies to the poor.

It is thus surprising to observe the widespread use of IBTs by utilities in cities where these two conditions are not likely to be met. The idea that households with low water use are poor and large users are rich has been challenged for a number of years, starting with Boland and Whittington (2000). Recent empirical evidence on the correlation between water use and income indicates that the correlation is positive but small (Whittington et al., 2015), which is consistent with findings that the income elasticity of residential water use is positive but small.[3] As far as the level of price is concerned, utilities (even in industrialized countries) are rarely covering their full costs and water is often subsidized, even in the higher blocks (Reynaud, 2016).

We argue that a water tariff structure (e.g. an IBT) performs better in terms of equity if it delivers a larger share of total subsidies to the poor, which we define in our calculations as households falling in the first quintile of the income distribution. Because IBTs involve a distortion from efficient pricing (which is achieved in the reference scenario based on a UP tariff structure), we present the trade-off between equity and economic efficiency, the latter

---

[1] Other authors (e.g. Szabo, 2015) have attempted to derive an "optimal" tariff from the perspective of the single criterion of economic efficiency. Such derivations typically depend on a similar set of (often implicit) assumptions as discussed in this paper.

[2] Among 165 water utilities surveyed by Global Water Intelligence in 71 low- and middle-income countries in 2013, 74% were using IBTs (Whittington et al., 2015).

[3] Estimates of income elasticity of residential water demand are often in the range 0.1-0.3 (Nauges and Whittington, 2010; Grafton et al., 2011).

measured by the deadweight loss that results from the implementation of the IBT.[4, 5] Finally, the financial cost recovery objective is taken into account through two constraints imposed in our simulation model: 100% cost recovery and 50% cost recovery. We ignore other objectives that water utilities may consider in the design of water tariffs, such as revenue stability and water conservation.

We find that IBTs perform poorly in terms of targeting subsidies to low-income households regardless of the magnitude of financial subsidies that a utility receives from high-level government. We also show that when cost recovery is low, the distribution of subsidies under IBTs is even worse if the correlation between water use and household income is high. IBTs introduce price distortions that induce economic efficiency losses, but we show that these welfare losses are relatively small, especially when households respond to average price.

This study adds to the empirical literature on subsidy targeting in the water sector. A number of authors have investigated how IBTs perform in terms of distributing subsidies to the poorest households but fewer have considered the trade-off between redistribution and economic efficiency. Borenstein (2012) asks similar questions for the residential electricity sector. He explores trade-offs between wealth transfer and economic efficiency using household billing data provided by three large Californian electric utilities combined with block-level income data provided by the United States Census Bureau, and finds that IBT tariffs for electricity do redistribute income from wealthier to poorer households but that transfers are fairly modest in comparison to substantial losses in economic efficiency.

## 2. Background

Policy makers and water professionals often rely too heavily on their intuition to assess how changes in water tariff regimes affect financial self-sufficiency, equity, and economic efficiency. Quantitative assessment of these impacts requires the specification of a set of nonlinear relationships with numerous parameters, and then formal simulation procedures to analyze how changes in the tariff structure and price levels affect outcomes of policy interest. Intuition is an unreliable guide for understanding the behavior of systems of nonlinear equations.

Policy makers often make implicit assumptions about both the parameters in this system of nonlinear equations and the functional relationships themselves. Three parameters in this system of nonlinear equations have received insufficient attention; they stand out as both

---

[4] We follow the approach of Borenstein (2012).

[5] "Deadweight loss" is the monetary measure of the loss in economic efficiency that results from the change from a UP to an IBT structure, taking into account impact on residential water users, the owners of the water utility (taxpayers if the utility is publicly owned), and taxpayers. A household's consumer surplus under a specific tariff is the difference between the household's willingness to pay (WTP) for piped water services and its bill. Total consumers' surplus is the summation of each household's surplus over the entire population (Total WTP – Total bills). The economic rents to the utility owners are always zero in our simulations because any shortfall in revenues is covered by taxpayers, and the utility's revenues never exceed its costs (by assumption). Taxpayers cover the shortfall in utility's revenues. This shortfall is zero under the assumption of 100% cost recovery and is strictly positive under the assumption of 50% cost recovery (equal to Total costs – Total bills). When moving from a UP tariff to an IBT structure, a household's consumer surplus increases [decreases] if the average price decreases [increases]. The total change in households' consumer surplus is calculated by summing over the change in surplus experienced by all households. The change in taxpayers' surplus is calculated by the change in the amount of subsidies they pay to the utility to cover the shortfall in revenues.

important to the outcomes of a tariff reform process and often uncertain in a particular local setting.

### *2.1. Correlation between household income and water use*

The first is the correlation between household water use and income. Water professionals typically assume that the correlation between household income and water use is high, i.e., that rich households use more water than poor households. There is, however, surprisingly little empirical evidence reported in the literature to support this assumption. To address this gap, we gathered household surveys from both developed and developing countries, and estimated the correlation between income and water use (measured here by the Spearman's $\rho$ ). We do not argue that this is a representative sample of households in either developed or developing countries, but in the absence of more comprehensive analyses, we suggest that it is likely to be illustrative.

We combined data from several sources (see Table 1). Evidence from industrialized countries mainly comes from the 2008 OECD Environmental Policy and Individual Behaviour Change (EPIC) survey, which includes eight OECD countries (Australia, Canada, France, Italy, South Korea, Netherlands, Norway, and Sweden).[6] About 1000 households were interviewed in each country about their environmental behavior and attitudes in different sectors (water, energy, waste, food, and personal transport) and their household income. For a subset of households in each country, the survey collected data on the household's annual water bill and annual water use.[7] In addition, we had access to water use and income information for a sample of 2240 households from 13 Portuguese municipalities.[8] Whittington et al. (2015) provide a description of the survey data covering the cities in four developing countries (Sri Lanka, El Salvador, Senegal, and Kenya) in Table 1.

Table 2 presents the mean and median household monthly water use (in $m^3$) and the mean household income (in US$ per month) for each of the eight countries covered by the OECD survey. Median household monthly water use varies from 8 $m^3$ in France to 18 $m^3$ in Korea. Mean monthly income varies from a low of US$3051 in Korea to US$7199 in Norway.

Table 1 shows the correlation between household income and water use in the surveys we analyzed. In four of the thirteen country data sets, the correlation was not statistically significant. For the remaining nine data sets the correlation was statistically significant and positive; it varied between +0.1 and +0.3. The correlation between household water use and income is thus typically (but not always) positive, but quite low. This means that there are many rich households that use small amounts of water, and many poor households that use large quantities of water.[9]

---

[6] For more details on the EPIC surveys and related publications, see OECD (2011) and http://www.oecd.org/env/consumption-innovation/households.htm (accessed, 5 October 2016).

[7] These variables are missing for a large number of households, for different reasons: either these households were not charged for water based on their consumption and did not receive a bill; or water charges were included in their rent and did not appear as a separate item; or they were not able (or not willing) to look for bills when answering the questionnaire. For more details on the water-specific data in the OECD survey, see OECD (2011) and Grafton et al. (2011).

[8] The database includes both primary data obtained from households (including income) and their actual monthly water use and billing data provided by utilities over the period July 2011-June 2012 (for more details, see Correia et al., 2015).

[9] The low correlation between household income and water use could also be explained by differences in household size between low-income and high-income households. Low-income households may have a

### *2.2. Relationship between marginal and average cost*

Efficient water pricing requires that households face a price that reflects the opportunity costs that their incremental use imposes on the water utility (and society), i.e. the full social marginal cost. However, water utilities often do not know the relationship between their average and marginal costs. Textbook expositions of natural monopolies present marginal costs below average costs, with increases in output that result in falling marginal costs, which pull down average costs (Boardman et al., 2011). In reality, some components of the water and wastewater delivery system exhibit economies of scale and falling marginal and average costs, but others may exhibit diseconomies of scale and increasing marginal costs. For example, as water scarcity increases and water utilities go farther from urban centers to find new raw water sources, the costs of the incremental water supply will increase. Similarly, adding desalinization facilities increases the cost of raw water supplies. But raw water supplies typically constitute only a small portion (5-10%) of the total costs of the water and wastewater services, so increasing costs of raw water supply may be offset by economies of scale in the piped networks and treatment components. Where the balance lies from a system-wide perspective is often unclear for a specific water utility at a particular time, and the relationship between the system-wide marginal and average costs is rarely explicitly stated in analyses of the consequences of tariff reforms.

### *2.3. Customers' response to marginal vs. average prices*

The tariff determines the relationship between average and marginal prices faced by a household. For example, increasing block tariffs create a price differential between the lower and higher blocks so that average volumetric prices are below marginal prices for customers who use more water than specified in the first (lifeline) block. Economic theory would suggest that a rational, observant customer would respond to the marginal price of the highest price block into which his household's water use falls, and might adjust his water use to avoid it falling into a higher price block of the tariff.

There are, however, three main reasons why customers might respond to average prices rather than marginal prices. First, complex tariff structures can be difficult to decipher for customers, and it may be too much trouble for households to try to figure out how to respond to marginal prices. Second, many utilities charge such low water prices (i.e., both average and marginal prices are low) that households simply may not find it worth the trouble to think about adjusting their water use to marginal prices. Third, households may have difficulty actually controlling the aggregate use of multiple household members, and thus the household unit may fail to respond to the marginal price signal.

Ito (2014) finds evidence that households in Southern California respond to average, not marginal water prices. We consider it likely that households in many developing countries also respond to average instead of marginal prices because water prices are low and tariff structures complex, and thus marginal prices are unlikely to be salient or known to households.[10]

But as tariffs are reformed to reflect a greater portion of the supply costs, marginal prices are likely to become more salient. If households then start to focus on what is driving their higher

---

lower per capita consumption than high-income households but their household water use may be larger if they have a larger family size. The analysis to follow is made at the household level to avoid specifying extra assumptions on the distribution of household size and its relationship with water use and income.

[10] See also Strand and Walker (2003) for further empirical evidence on households' response to average rather than marginal prices in several cities from Central America.

water bills, it seems plausible that households will shift from responding to average prices to responding to marginal prices. There is little empirical evidence on this issue, and water professionals rarely make explicit their assumption about whether households will respond to average or marginal price. Yet it is a critical parameter in a simulation model of the consequences of a tariff reform (see also Borenstein, 2012, for a related discussion).

## 3. Modeling Strategy, Assumptions, and Data

We assume that the initial, status quo situation is a municipality in which the water utility uses a UP tariff to determine the water bills of its customers, i.e. all customers pay the same volumetric price no matter how much water they use. This utility is assumed to operate under constant returns to scale from a system-wide perspective. In other words, economies of scale in one component of the municipality's water and wastewater supply system are counterbalanced by diseconomies of scale in other components, so that average costs equal marginal costs. This assumption is consistent with empirical evidence that average-sized utilities are characterized by a scale factor equal or close to one in some industrialized countries (Saal et al., 2013).

The uniform volumetric price charged to households is equal to the full average cost of supplying water and wastewater services, and this price is the efficient marginal price that reflects the full cost of incremental supply (i.e., 100% cost recovery). There is no subsidy distributed to any of the households and no price distortion. We then ask the question, "What would be the consequences of a change from this UP tariff structure to an IBT design in terms of equity (i.e., the share of the subsidies that goes to the first income quintile) and economic efficiency, under two different levels of cost recovery (50% and 100%)?"

We model the consequences of moving from the UP structure to nine different IBT designs (Table 3). All of the IBT designs have two price blocks: 1) a lower (lifeline) block, and 2) an upper block.[11] We examine IBTs with three different sizes of lifeline blocks: 5 cubic meters ($m^3$), 10 $m^3$, and 15 $m^3$ per month. We assume that the households' monthly water bills are determined by a volumetric component and a fixed charge. For each of the three sizes of lifeline blocks, we consider three levels of fixed charge: zero, US$10 per month, and US$15 per month. The levels of the fixed charge and sizes of the lifeline block have been chosen such that they reflect common practices in water and wastewater utilities globally.

A challenge analysts face when they want to understand how changes in tariffs affect poor households is that the utility's customer billing records do not include information on households' income and other socioeconomic and demographic characteristics. If a connection is metered and used solely by members of the household, a utility knows how much water the household uses, its water bill, and the tariff structure. But analysts who want to study the equity consequences of a tariff reform need a procedure for matching customers billing records with household income (Fuente et al., 2016).

Our approach to link household water use and income follows Whittington et al. (2015). We assume a hypothetical community of 5000 households, each with a metered, private connection to a piped water and wastewater network. The analysis of households with shared piped

---

[11] In most water and wastewater utilities using IBTs, the number of blocks is greater than two (see Figure 1 in Whittington et al., 2015). However simulating IBTs with more than two blocks would increase the size of the possible choice set in terms of IBT parameters (size of the blocks, prices in each block). We believe that useful and relevant insights on the trade-off between equity and economic efficiency are already well captured with a two-block IBT.

connections and unmetered connections is outside the scope of this paper. But the widespread presence of unmetered connections does not strengthen the argument for IBTs because IBTs can only be used to determine the water bills for households with metered connections. Using an IBT to determine the water bill for a group of households sharing a metered connection actually drives the average price of households in the group higher because more water use occurs in the higher priced blocks. To the extent that poor households are more likely to use shared connections (and to share a connection with more households), they will be adversely affected by an IBT (Whittington, 1992).

We focus on household water use instead of per capita water use for two reasons. First, because our data are hypothetical, extending the analysis to compare household versus per capita results would have required making additional (ad-hoc) assumptions on the distribution of household size and its relationship with the distribution of water use and income. Assumptions on household size (in order to calculate per capita water use) would add another layer of uncertainty into our simulation model. Second, it is typically not possible to set tariffs that account for household size. Although special tariffs for large households have been deployed in some Spanish cities (Arbués and Barberán, 2012), they remain extremely uncommon globally.[12]

On each of these 5000 households, we calculate the effects of the shift from a UP (that achieves 100% cost recovery) to an IBT structure, under two different cost recovery constraints (50% or 100%). Individual household data on water use and income are obtained by draws from two log-normal distributions calibrated using the OECD household survey data described in the previous section.

From the reported household-specific data on water use and income from these eight OECD countries, we estimate a log-normal distribution for household monthly water use with location parameter $\mu = 2.61$ and scale parameter $\sigma = 0.91$ (which corresponds to a mean of 21 m$^3$/month and a median of 14 m$^3$/month). Similarly, we use these OECD data to estimate a log-normal distribution for household monthly income with location parameter $\mu = 8.21$ and scale parameter $\sigma = 0.58$ (which corresponds to an average monthly income of US$4351 and a median of US$3678).

We use a procedure proposed by Johnson and Tenenbein (1981) and described in Whittington et al. (2015) to draw household-specific pairs of income and water use data that maintain an assumed overall correlation for the 5000 households. Thus, an important assumption embedded in our model is this assumed correlation between water use and income. We run simulations under two different assumptions about the correlation between water use and income. We first assume a low correlation (Spearman's $\rho$ of +0.1), which seems to be realistic based on the empirical evidence presented in Table 1. We then test to see how our findings change under the assumption of a high (but unrealistic) correlation between water use and income (+0.8).

We assume a price elasticity of demand of -0.2, in line with empirical evidence from a large set of countries that price elasticity is quite often in the range -0.1 to -0.4 (Nauges and Whittington, 2010; Grafton et al., 2011). When the new IBT tariff is put in place, households will face a price that is different from the uniform volumetric price. If a household chooses a quantity and associated price under the IBT that is lower than with the uniform volumetric price, its water

---

[12] One reason why such tariffs are unpopular is that they require utilities to get (reliable) information on the size of the households that they supply, and keep these data up-to-date. In most low and middle-income countries, this task is not administratively feasible at the present time. Even in high-income countries, the vast majority of water utilities do not have this capability.

use will increase (because of the assumed negative non-zero price elasticity). In contrast, if a household chooses a quantity with a higher price under the IBT than with the uniform volumetric tariff, its water use will decrease.

We assume that households respond to average price rather than marginal price. We test the effect of assuming that households respond to marginal price (see "Model Extensions" below). The average cost of supplying water and wastewater services is assumed to be US$5 per cubic meter. For each specific IBT tariff design presented in Table 3, we simulate two levels of cost recovery: 100% or full cost recovery (i.e. the bills paid by the 5000 households generate revenues that exactly cover costs) and 50% cost recovery (i.e. the revenue from the bills only covers half of the costs).

Because there is an infinity of pairs of prices in the IBT with two blocks (price in the lifeline block and price in the upper block) that could achieve the specified cost recovery level, we assume that the volumetric price of water in the lower block will always be set at half of the price of the upper block. We needed to set one price (either the price in the first block or the price in the second block) in order to be able to find a unique solution that achieves the pre-defined cost recovery level. We decided to set the volumetric price in the first (lifeline) block to half the price in the upper block because this approximates how many utilities with IBTs set prices in different blocks.[13] As a consequence of this assumption, the only unknown parameter is the price of the upper block. Our simulation program solves for the price in the upper block that achieves the specified cost recovery constraint, taking into account that the quantity of water a household uses responds to the average price change.

We assume that household's monthly water use has a lower limit of 5 $m^3$ below which it is insensitive to price changes. We run a total of 36 scenarios (see Appendix A for characteristics of each scenario). Each scenario is run 100 times, and we report the average outcome over the 100 replications in terms of the quantity of water used, the water bill paid, and the performance indicators for our three criteria.

We assume a zero income elasticity of water demand.[14] The income elasticity is usually found to be low, around +0.1 to +0.3, and the bill-to-income ratio is generally in the range 1-3%. As a consequence, the quantity effect induced by the income change would be insignificant, and we assume it can be ignored. A dynamic simulation model of a tariff reform process would need to incorporate exogenous changes in household income that would be anticipated over the planning horizon of the simulation.

Table 4 summarizes the main assumptions underpinning the calculations, both the assumptions that are varied and those that are not.

---

[13] We had access to the 2011 Global Water Intelligence database on water and wastewater utilities worldwide. 150 out of the 308 utilities listed in the database used IBTs. For these 150 utilities we calculated the following ratio: price in lifeline block/price in the second block. This ratio varied from 0 (when water in the lifeline block is free) to 0.97. The mean was 0.47 and the median was 0.52. For more information on Global Water Intelligence utility surveys, see https://www.globalwaterintel.com/; accessed 5 October 2016.

[14] Income effects are also ignored in Borenstein (2012). We are aware that the assumption of a zero income elasticity of demand is inconsistent with the assumption of a 0.8 correlation between water use and income. The high correlation case, which is unrealistic, should be seen simply as an exercise to illustrate how our main findings would change if water use and income was highly correlated.

## 4. Quantifying the Performance of Alternative Tariff Structures in terms of Three Criteria: Financial Self-Sufficiency, Equity, and Economic Efficiency

The implementation of a new tariff in a community changes the prices households face, the quantity of water they use, and the amount of the water bill they pay to the utility. We assess how these changes affect two criteria: distribution of subsidies (equity) and economic efficiency (welfare gains and losses), under two different levels of cost recovery for the new IBT (50% and 100%). We report the consequences of the change in tariff structure from a UP design (where cost recovery is always 100%) to each of the nine IBT designs in terms of these two criteria under the two cost recovery levels.[15]

### *4.1. Financial self-sufficiency (cost recovery)*

The cost recovery level (either 50% or 100%) enters as a constraint in our simulation model. Financial self-sufficiency requires that the revenues the utility receives in total from all its customers (5000 households in our calculations) are equal to the total costs of providing these customers with water and wastewater services. There is a continuum from zero cost recovery (in which case the utility provides all of its customers with free services) to 100% cost recovery (the utility does not receive any financial subsidies from higher levels of government). The majority of water utilities in low-income countries fall on the low end of this continuum; few achieve more than 50% cost recovery. Many operate with only 10-25% cost recovery.[16] Some of their operating costs, and essentially all of their capital costs, are paid by higher-level government authorities or donors. Even in high-income countries relatively few water utilities actually achieve 100% cost recovery (cf. Table 1 in Reynaud, 2016).

If a water utility does achieve 100% cost recovery, the financial self-sufficiency objective is fully satisfied. But this does not necessarily mean that all of its customers pay the full costs of the services they receive. But if one group of households pays less than its full costs of service, another group of households must pay more than its costs of services so that in aggregate the revenues received from all its customers equal the costs of serving all customers.

If a water utility achieves 50% cost recovery, financial self-sufficiency is not achieved, but perhaps the equity criterion is better than if 100% cost recovery was achieved. But even if revenues only cover 50% of the total costs of serving the utility's customers, this does not necessarily mean that all customers pay less than their costs of service. It is still possible that some customers could pay more than their costs of services, in which case others would pay much less.

The water bill is calculated for each of the 5000 households using the household's water use ($Q_i$) under the new tariff structure. For example, if the water utility used an IBT tariff structure with a lifeline block of 10 m$^3$, the price in the upper block was $P^*$, there was no fixed charge, and $Q_i > 10$ m$^3$, the water bill for household $i$ ($WB_i$) would be …

$$WB_i = [10\text{ m}^3 \times 0.5 \times P^*] + [(Q_i - 10\text{ m}^3) \times P^*] \qquad (1)$$

---

[15] The consequences of moving from an existing IBT tariff to a uniform volumetric tariff would be the reverse (the negative) of the changes in criteria reported here.

[16] Using data from about 4000 utilities from over 130 countries over the 2006-2011 years, Danilenko et al. (2014) report that: "the percentage of utilities [in low-income countries] that could not cover even operation and maintenance (O&M) costs increased from 28 percent in 2000 to 50 percent in 2010. Lower middle-income countries were the most affected, with 70 percent not able to cover their O&M costs. Upper middle-income countries seem less affected, partially because many continued to grow their economies rapidly; but even among these countries, 40 percent of water and sanitation utilities were not able to cover their basic O&M costs."

Assume the average total production cost per cubic meter is $AC$, then the subsidy received by household $i$ ($SUB_i$) is[17] …

$$SUB_i = (AC \times Q_i) - WB_i \tag{2}$$

The total revenues received by the utility from the 5000 households ($TOTREV$) and the total subsidies provided to the 5000 households ($TOTSUB$) are …

$$TOTREV = \sum_{i=1}^{5000} WB_i \tag{3}$$

$$TOTSUB = \sum_{i=1}^{5000} SUB_i = AC \times \sum_{i=1}^{5000} Q_i - TOTREV \tag{4}$$

Cost recovery is 100% when TOTSUB = 0. Cost recovery is 50% when …

$$TOTSUB = TOTREV, \text{ and} \tag{5}$$

$$TOTSUB + TOTREV = AC \times \Sigma^{5000} Q_i \tag{6}$$

*4.2. Equity*

Concerns about the equitable provision of municipal water and wastewater services can be defined and measured in numerous ways. For example, one could calculate an affordability indicator that expresses each household's water bill as a percent of its income. If water and wastewater expenditures exceed a specified percentage, then the tariff has generated water bills for at least some households that are "unaffordable." This is then judged to be a negative attribute of that specific tariff design. Alternatively, one could also analyze whether similar households received similar water bills. If they did not, this might be considered inequitable even if the water bills were affordable.

In this paper we propose to measure equity by reporting the distribution of subsidies across different income groups. We calculate the share of the total subsidies received by households in each income quintile $j$ ($ShareSUB_{IQj}$) as …

$$ShareSUB_{IQ_j} = \sum_{i \in IQ_j} SUB_i \Big/ TOTSUB \qquad \text{for j = 1, …, 5} \tag{7}$$

Because this result is dependent on the specific draw of 5000 household income and water use pairs, we do this calculation a hundred times, and then calculate the average of the share of the total subsidies received by households in each income quintile $j$ ($ShareSUB_{IQj}$) over the hundred replications. The result is our best estimate of the share of total subsidies received by households in each income quintile for the specific IBT tariff under consideration. We then compare the change in the distribution of subsidies under the UP and new IBT tariff. We define a tariff that targets a larger percentage of the available subsidies to households in the first income quintile as more equitable.

---

[17] Depending on the level of the average cost and characteristics of the water tariff, the subsidy could be negative. In this case households in one income quintile would provide cross-subsidies to households in other income quintiles.

### *4.3. Economic efficiency*

We calculate the welfare change due to the shift from the status quo UP design to one of the new IBT alternatives in Table 3 by measuring the change in consumer's surplus resulting from the price change that each of the 5000 households experiences. We use the calculation method proposed by Hausman (1981), who showed that, if the household's water demand function is of the log-log form (the most commonly estimated functional form), then the change in surplus can be computed analytically, as described below.

A log-log household's demand function for water is specified as follows:

$$\ln Q = \alpha + \beta \ln(P) + \sum_{j=2}^{J} \delta_j \ln(X_j) \tag{8}$$

where $Q$ is household's water use, $P$ is the average price and $X$ a set of household characteristics. $\beta$ is the price elasticity of demand. If we apply the exponential to both sides of equation (8), we have:

$$Q = \exp\left[\alpha + \beta \ln(P) + \sum_{j=2}^{J} \delta_j \ln(X_j)\right] = e^{\alpha} P^{\beta} \prod_{j=2}^{J} X_j^{\delta_j} = A.P^{\beta} \text{ with } A = e^{\alpha} \prod_{j=2}^{J} X_j^{\delta_j} . \tag{9}$$

So the demand function for water is equivalently written as:

$$Q = A.P^{\beta} \text{ where } A = e^{\alpha} \prod_{j=2}^{J} X_j^{\delta_j} \tag{10}$$

The change in surplus ( $\Delta S$ ) following a change in price from $P_0$ (the UP price) to $P_1$ (the average price under an IBT) is calculated from the demand curve as:

$$\Delta S = -\int_{P_0}^{P_1} A.P^{\beta} dP = -\frac{A}{1+\beta}\left(P_1^{(1+\beta)} - P_0^{(1+\beta)}\right) \tag{11}$$

The change in surplus depicted in (11) remains valid whether $P_1$ is greater or less than $P_0$, i.e., $P_1$ (the average price under the new IBT) can be above or below the UP price $P_0$, and the calculation of the surplus experienced by the household (either positive or negative) remains correct.

In order to calculate the change in surplus, one needs information on $P_0$, $P_1$, price elasticity of demand and $A$. Our simulation program generates the initial water use for each household ($Q$), and we have made the assumption that the price elasticity $\beta$ is -0.2. The initial UP price ($P_0$) is known since we assume uniform volumetric pricing (for 100% cost recovery, $P_0$= US$5 per $m^3$). The average price under the IBT is calculated for each household once their water use is determined following the change to an assumed IBT design. The only term missing in the calculation of the change in the household's consumer surplus is $A$, which we infer from $Q$, $P$ and $\beta$ using (10):

$$A = \frac{Q}{P_0 \beta} \tag{12}$$

In addition to the change in consumer surplus experienced by the household, we measure the deadweight loss suffered by society as a result of the shift to an IBT structure. For this calculation we estimate the subsidies taxpayers are paying to the utility when cost recovery is lower than 100%.

## 5. Results

### *5.1. Benchmark Case: IBT 0-10: Cost recovery = 50%; Income-Water Use Correlation = +0.1*

We first examine the consequences of our benchmark case, a shift from the uniform volumetric price tariff (UP-0) to an IBT with no fixed charge, cost recovery of 50%, and a correlation between household income and water use of +0.1. These assumptions approximate conditions in numerous cities around the world. Our simulation model finds prices for the IBT that achieve 50% cost recovery: US$1.6 per $m^3$ for the first (lifeline) block and US$3.2 per $m^3$ for the upper block.

On average over the 100 replications, 1753 households (35%) fall into the lifeline block and 3247 households (65%) fall into the upper block. Average monthly household water use and average monthly water bill vary modestly across income quintiles from 20 $m^3$ and US$49 respectively in the poorest quintile to 26 $m^3$ and US$66 in the richest.

The assumption that cost recovery is 50% means that there are substantial subsidies to be distributed from taxpayers to the utility's customers under the IBT tariff.[18] However, our results show that, from an equity perspective, the shift from a UP tariff to this IBT has only delivered a small portion of these subsidies to households in the poorest quintile. Under the IBT households in the poorest quintile receive only 18% of the total subsidies (an average monthly subsidy of US$51); households in the richest quintile receive 22% (an average monthly subsidy of US$63), a proportionately larger share.

The main reason that the IBT has not delivered subsidies more effectively to poor households is that the price of water and wastewater services in the upper block is below the average cost of providing these services, so all households are receiving subsidies and the more water a household uses, the more subsidies it receives. Because the correlation between income and water use is positive (although low), rich households on average use more water than poor households and thus receive more subsidies. This situation, in which the price of water in the upper block of an IBT is below average cost, is quite common in many water utilities, especially in low-income countries. We conclude that in the benchmark case, the shift from the UP to the IBT tariff is not attractive from the perspective of our equity criterion.

From the perspective of economic efficiency, the results in Table 5 show that the shift to the IBT-0-10 has resulted in welfare gains (increased consumer surplus) to all households because all households experience a reduction in their average price compared to the UP. These welfare gains are less than the value of the subsidies received because at the margin the subsidized water is not worth as much to a household as it costs the utility to supply. The average monthly welfare gain to households is US$53, but this comes at a cost to taxpayers of US$57. The average welfare gain for households in the poorest quintile (US$47) is less than the welfare gain for

---

[18] Of course, there is substantial overlap between taxpayers and household water users. It is possible that the community, in aggregate, may self-finance the cost recovery shortfall, but equity concerns may arise from the incidence of local taxes as compared to the water tariff subsidies. In some local situations, poor households may avoid paying most taxes. It is also possible that some or all of the financial shortfall may be financed by central government or by international aid agencies. Another way of financing the shortfall (popular in both industrialized and developing countries) is through deferred maintenance, which amounts to a generational shift in cost incidence.

households in the richest quintile (US$58). The resulting societal (deadweight) loss is US$22,938 per month for the community of 5000 households (approximately US$4.6 per household per month).

The result of the shift from a UP tariff to this benchmark IBT has reduced economic efficiency and induced some societal loss. With a 50% cost recovery constraint, water use is subsidized but rich households receive a larger proportion of subsidies than poor households. In other words, there is no trade-off between equity and economic efficiency from this policy intervention given our assumptions.

### *5.2. What happens if the size of the lifeline block changes? (IBT-0-5, IBT-0-15)*

Figure 1 illustrates how changes in the size of the lifeline block affect the average water price. As shown, a small lifeline block (e.g. 5 $m^3$) entails higher average prices because at low levels of water use a higher proportion of a household's total water use is charged at the rate in the upper block. However, changing the size of the lifeline block has only a small effect on the water use, water bills, the average subsidy received, and the percent of subsidies received by different income quintiles, compared to the benchmark case.

Our simulation model finds prices for IBT-0-5 that achieve 50% cost recovery: US$2.4 per $m^3$ for the first (lifeline) block and US$4.9 per $m^3$ for the upper block. Reducing the lifeline block from 10 $m^3$ to 5 $m^3$ results in average monthly water use of 23 $m^3$, the same as the benchmark case, ranging from 20 $m^3$ in the lowest quintile to 26 $m^3$ in the richest quintile. The average water bill is US$57 (the same as in the benchmark case), ranging from US$49 in the poorest quintile to US$66 in the richest quintile. The average monthly subsidy is US$57 (same as the benchmark case), ranging from US$51 in the poorest quintile to US$64 in the richest quintile. With a lifeline block of 5 $m^3$, the welfare gains to households are essentially the same as the benchmark case (US$53). Deadweight losses decrease about 5% because more households respond to an average price closer to the marginal cost.

Increasing the size of the lifeline block has small effects in the opposite direction. Our simulation model finds prices for the IBT-0-15 that achieve 50% cost recovery: US$2.4 per $m^3$ for the first (lifeline) block and US$4.9 per $m^3$ for the upper block. Increasing the lifeline block from 10 $m^3$ to 15 $m^3$ results in average monthly water use of 23 $m^3$, ranging from 20 $m^3$ in the lowest quintile to 26 $m^3$ in the richest quintile. The average water bill is US$57 (the same as in the benchmark case), ranging from US$49 in the poorest quintile to US$66 in the richest quintile. The average monthly subsidy is US$57 (same as the benchmark case), ranging from US$51 in the poorest quintile to US$64 in the richest quintile. With a lifeline block of 15 $m^3$, the welfare gains to households are almost the same as in the benchmark case (<1% difference). Deadweight losses increase about 3% because the price distortion is increased as more households respond to an average price farther from the marginal cost.

Reducing the size of the lifeline block decreases deadweight losses without much effect on the distribution of subsidies across income quintiles. But the key message is that changing the size of the lifeline block does not change our main result that the shift from a uniform volumetric tariff to this benchmark IBT has reduced economic efficiency and done nothing to improve equity when cost recovery is 50% and the correlation between household income and water use is +0.1.

### *5.3. What happens if a positive fixed charge is added to the volumetric component of the IBT? (IBT-10-10, IBT-15-10)*

Adding a positive fixed charge to the volumetric component of a water bill is common practice.[19] The fixed charge is especially attractive to utility managers because it increases revenue stability. Figure 2 illustrates how the average water price (US$/m$^3$) changes as a function of monthly water use (m$^3$) under three IBT tariffs with a positive fixed charge and two sizes of the LLB: 5m$^3$ and 10m$^3$ per month. As shown, a positive fixed charge results in high average water prices at low levels of water use. The average price first falls as water use increases as the fixed charge is spread over higher water use, but then rises as more and more water is billed at the price of the upper block.

Our simulation model finds prices for IBT-10-10 that achieve 50% cost recovery: US$1.3 per m$^3$ for the first (lifeline) block and US$2.6 per m$^3$ for the upper block. Adding a fixed charge of US$10 per month while maintaining the 50% cost recovery target again results in similar average monthly water use and water bills as the benchmark case. Water bills for households in the poorest quintile and the subsidies they receive are essentially the same as for the benchmark case. Households in the richest quintile still receive a larger share of the total subsidies (23%) than households in the poorest quintile (18%).

With a fixed charge of US$10 per month, the welfare gains to households are almost the same as in the benchmark case. Deadweight losses decrease about 8% because more households respond to an average price closer to the marginal cost. Adding a fixed charge does create a modest efficiency vs. equity trade-off: a higher fixed charge increases economic efficiency at the expense of poor households. Increasing the size of the fixed charge (e.g. IBT-15-10) accentuates this trade-off. But again the key message is that adding a positive fixed charge does not change our main result that the shift from a UP tariff to this benchmark IBT has reduced economic efficiency and done nothing to improve equity.

### *5.4. What are the consequences of increasing the cost recovery constraint to 100%? (IBT-0-10)*

Table 6 shows the changes that result from a shift from an UP tariff to an IBT (with a lifeline block of 10 m$^3$ and no fixed charge) in which the prices in the lower and upper blocks are set to achieve 100% cost recovery. One can also compare the results in Table 6 with the results for the benchmark case presented in Table 5 to see the consequences of increasing the cost recovery target from 50% to 100%, holding other parameters in the simulation model constant.

The implications of increasing the cost recovery constraint from 50% to 100% are far reaching. Our simulation model finds prices for IBT-0-10 that achieve 100% cost recovery: US$3.2 per m$^3$ for the first (lifeline) block and US$6.4 per m$^3$ for the upper block. Because the simulation model forces the 100% cost recovery target to be achieved, there are no subsidies provided by taxpayers. There are, however, cross-subsidies between households. On average over the 100 replications, 3614 households receive subsidies, and 1386 households make "excess payments" above their costs of services. The average monthly water use of the 3614 households that receive subsidies is only 11-12 m$^3$ in all five quintiles. Their average water bill is US$46, and the range across the quintiles is small (from US$43 per month in the poorest quintile, to US$49 in the richest).

---

[19] A policy allowing a household to finance its initial connection cost to the piped network, and making periodic payments on its water bill, would have a similar effect on average prices as adding a positive fixed charge to the volumetric component of a household's water bill.

One would hope that rich households cross-subsidized poor households, but Table 6 shows that this is not the case. The 3614 households receiving subsidies are distributed relatively evenly across the income quintiles, from 770 households in the poorest quintile to 673 households in the richest. These 3614 households receive an average monthly subsidy of US$11.3, with little variation in the size of the subsidy across income quintiles (from US$11.4 in the poorest quintile to US$11.2 in the richest). Only 21% of the cross-subsidies are received by households in the poorest quintile. So just as is the case when subsidies are paid by taxpayers in the 50% cost recovery benchmark case, the cross-subsidies in the 100% cost recovery case are not well-targeted to the poor.

The 1386 households that make "excess payments" above their costs of services are distributed throughout the income distribution. Only 24% of these households making excess payments are in the richest quintile. These 1386 households use much more water per month than the households receiving subsidies. Their average monthly water use and average water bill are 45 $m^3$ and US$254 respectively, ranging from 43 $m^3$ and US$241 in the poorest quintile to 47 $m^3$ and US$267 in the richest quintile. The fact that these water bills seem so high reinforces our point that few water utilities even in industrialized countries actually achieve 100% cost recovery.[20]

For the 3614 households receiving subsidies, they experienced an average welfare gain of US$11 per month compared to the UP tariff. In the benchmark case the average welfare gain was US$53 per month for all households, so these 3614 households receiving subsidies are unsurprisingly much worse off in the 100% cost recovery case than with 50% cost recovery. For the 1386 households making excess payments, their average welfare loss is US$30 per month, instead of a welfare gain of approximately US$53 in the 50% cost recovery case. But taxpayers benefit compared to the benchmark case because they no longer provide any subsidies. There is still a small deadweight loss for society (about US$0.40 per month per household) that results from the price distortion introduced by the IBT.

Cost recovery of 100%, coupled with the IBT-0-10 tariff, shifts the costs of provision from taxpayers to water users, and creates a cross-subsidy from large water users to small water users. But because the correlation between household income and water use is low, the cross subsidies are not flowing from rich to poor households. There are many poor and middle income households with high water use cross-subsidizing other middle-income and rich households.

The shift to 100% cost recovery compared to our benchmark IBT-0-10 with 50% cost recovery has achieved the financial self-sufficiency objective and shifted the financial costs away from taxpayers. The societal deadweight losses are almost eliminated compared to the benchmark case but it is difficult to conclude that equity has been improved compared to the UP tariff because the cross-subsidies are poorly targeted. Large water users are providing modest cross subsidies to low water users, but many of the households making excess payments are poor and many of the households receiving subsidies are rich.

### *5.5. What happens to the results of the benchmark case (IBT-0-10) if the correlation between household income and water use is high (+0.8) instead of low (+0.1)?*

Intuition might suggest that equity (i.e. the share of subsidies targeting poor households) would

---

[20] A monthly bill of US$254 corresponds to about 6% of the household average income (US$4351) in our setting, which is far above the average affordability ratio estimated in industrialized countries, usually in the range 0.5-2% (cf. Table 7 in Reynaud, 2016).

improve if the correlation between household income and water use is higher, but this is incorrect if the cost recovery constraint is 50%. Assuming a 50% cost recovery constraint and a correlation between household income and water use of +0.8, our simulation model finds prices for IBT-0-10: US$1.6 per $m^3$ for the first (lifeline) block and US$3.1 per $m^3$ for the upper block. Average monthly household water use is 23 $m^3$ and average water bill is US$57, ranging from 8 $m^3$ and US$13 in the poorest quintile to 39 $m^3$ and US$144 in the richest. But households in the poorest quintile only receive 9% of the total subsidies (corresponding to an average of US$25 per household); households in the richest quintile receive 39% (or US$112 per household). IBTs do even worse targeting subsidies to poor households when the correlation is high than when it is low if cost recovery is also low (as in the benchmark case). This is because all of the water that the utility sells is sold below average cost, so the more water a household uses, the more subsidies it receives—and rich households use much more water than poor households if the correlation is high.

If the correlation were +0.8, the average household welfare gain would be US$53, but it is only US$22 for households in the poorest quintile, compared to US$105 for households in the richest quintile. So households in the poorest quintile would be much worse off than in the benchmark case, in which their average welfare gain was US$47 per month.

There are no cross-subsidies in this case, so all the subsidies received by households are paid by taxpayers. Because the value of the total subsidies paid by taxpayers is greater than the welfare gain received by households, a societal deadweight loss of US$22,913 per month remains for the community of 5000 households (approximately US$4.6 per household per month), essentially equivalent to the deadweight loss in the benchmark case.

We emphasize that we consider this high correlation case for illustrative purposes. The correlation between household income and water use is not something that the utility or social planner can control, and it is unlikely that the correlation will be this high (+0.8).

### *5.6. What happens if both the cost recovery constraint is high (100%) and the correlation between income and water use is high (+0.8)?*

To the best of our knowledge, this combination of parameters does not exist in any water utility today. A small portion of water utilities in industrialized countries may be recovering close to full long run supply costs, but most are not. The majority of water utilities in developing countries are recovering less than 50% of total costs, many much less. And although the data on the correlation between household income and water use are sparse, there is no indication from any of our datasets (Table 1) that the correlation is above +0.5, certainly not as high as +0.8. Nevertheless, it is important to consider this case because it is here that the IBT does in fact offer some advantages in terms of equity compared to the UP design, and this is the case that many water professionals (mistakenly) have in mind when they recommend IBTs.

Figure 3 shows the distribution of subsidies across household income quintiles for four combinations of percent cost recovery and correlation between household income and water use for an IBT with a lifeline block of 10 $m^3$ and no fixed charge: 1) 50% cost recovery; +0.1 correlation (NW cell); 2) 50% cost recovery; +0.8 correlation (NE cell); 3) 100% cost recovery; +0.1 correlation (SW cell); and 4) 100% cost recovery; and+0.8 correlation (SE cell). Case 1 is our benchmark case. Moving from Case 1 to Case 4 (from NW to SE) does improve the distribution of subsidies across income quintiles substantially. Case 4 is the only one of the four cases in which poor households receive a much higher proportion of the total subsidies than rich households. But note that Case 4 requires 100% cost recovery, so although the distribution of subsidies is improved, the absolute magnitude of the subsidies delivered is small.

The welfare gains to poor households are much smaller in Case 4 than in Cases 1 and 2. The main beneficiaries of the 100% cost recovery constraint are taxpayers, not poor households (although poor households also may pay taxes). Moreover, the correlation between household income and water use is exogenous (outside the control of the water utility), so a water utility with a low correlation (Cases 1 and 3) cannot simply choose to move to Case 4 to improve subsidy targeting.

Figure 4 presents the cumulative distribution of subsidies as a function of income percentile for the four cases in Figure 3. The two cases with a correlation between household income and water use of +0.1 are close to 45-degree lines, meaning that subsidies are evenly distributed to households throughout the income distribution. The two cases with a correlation between household income and water use of +0.8 are different. The case with 50% cost recovery and a correlation of +0.8 shows a distribution of subsidies skewed toward the rich. The case with 100% cost recovery and a correlation of +0.8 shows a distribution of subsidies skewed toward the poor.

We believe most water utilities, especially in developing countries, are probably closer to Case 1 in the typology shown in Figure 3 than to the other three cases. Utilities in industrialized countries are on a continuum between Case 1 and Case 3. Although some water professionals probably imagine that there are many utilities in Case 2, we think this is very unlikely. But this is, in fact, fortunate because in Case 2 households in the richer quintiles receive the majority of the subsidies under IBTs. Some water utility professionals may imagine that they are in Case 4 where IBT tariffs target subsidies to households in the poor quintiles most effectively, but we consider this unlikely on two counts: 1) few utilities are actually recovering 100% of full costs; and 2) there is no evidence that the correlation between household income and water use is this high.

### *5.7. Summary of results*

Tables 7 and 8 summarize our results, comparing each of the nine IBT designs in terms of our two criteria, for two cost recovery constraints (50% and 100%) and the two assumed correlations between household income and water use. As shown in Table 7, if the correlation between household income and water use is low, subsidies are always poorly targeted, regardless of the level of cost recovery, the size of the lifeline block, or the size of the fixed charge. With a low level of cost recovery (50%), the magnitude of the subsidy to households in the poorest quintile is substantial (about US$50 per household per month), but relatively insensitive to changes in the IBT design. Increasing the size of the fixed charge makes the targeting of subsidies to poor households slightly worse because it increases the average price of water to households with low water use (Figure 2). With 50% cost recovery, societal efficiency losses are relatively low (about US$4-5 per household per month) because the assumption that households respond to average prices keeps the price distortion modest.

Increasing cost recovery to 100% reduces the magnitude of the average subsidy to poor households (to about US$3-13 per household depending on the tariff design), and does not improve the targeting of subsidies to poor households. Increasing cost recovery to 100% does essentially eliminate the societal efficiency losses. Increasing the fixed charge and reducing the size of the lifeline block raise average prices at low levels of water use and further reduce economic efficiency losses.

None of the tariff designs presented in Table 7 accomplish the equity objective of targeting the majority of subsidies to poor households. Efficiency losses are modest with 50% cost recovery and insignificant with 100% cost recovery if households respond to average prices. Increasing the cost recovery target (from 50% to 100%) reduces the subsidy to poor (and rich) households but also reduces the burden on taxpayers. Importantly, with a low correlation between household water use and income, none of the IBT designs improve upon a simple, transparent volumetric tariff structure in terms of any of the three objectives.

Table 8 summarizes the results for the case where the correlation between household income and water use is high. The targeting of subsidies to poor households is improved for a 100% cost recovery target (poor households receive 39% of total subsidies), but only if there is no fixed charge and if the lifeline block is small. In these results, the effect of adding a fixed charge falls heavily on poor households, reducing both the percentage of subsidies and the magnitude of the subsidy received by poor households. Economic efficiency losses are similar to those in Table 7 (about US$4-5 per household per month for a 50% cost recovery target, and minimal for a 100% cost recovery target).

## 6. Model Extensions

There are numerous directions in which our calculations could be extended. Perhaps the three most important are: 1) to explore the implications of changing our assumption that households respond to marginal instead of average prices; 2) to explore the implications of our assumption that the utility operates under constant returns to scale; and 3) to report the performance of the alternative tariff structures for additional criteria, such as water conservation.

### *6.1. What happens if households respond to marginal instead of average prices?*

The question of whether customers respond to the average or marginal price depends on how familiar customers are with the tariff structure and how they interpret changes in their water bill. It seems likely that most customers are not familiar with the specific prices and charges embedded in their water tariff. Also, they probably do not routinely monitor their water use and are largely unaware of the amount of water they use for different purposes. How then do they interpret the price signal they receive from their water bill? One possibility is that they do a static analysis and simply divide their monthly water bill by the amount of water they use to calculate the average price they pay per cubic meter. Then they respond to this average price to determine the amount of water they use the following month.

A second possibility is that they respond to the change in their current monthly water bill from their previous water bill. They might divide the change in their water bill by their estimate of the change in the quantity of water they used. Except for water use that occurs near the transitions of an IBT, this price signal approximates the customer's marginal price.

All 36 scenarios have been run under the assumption that households react to changes in marginal price instead of the average price. If households respond to marginal prices instead of average prices, the methodology described in Section 4.3. can be applied with $P_1$ the (marginal) price of the block in which the household's water use falls, but the calculation of the change in surplus needs to be adjusted. As shown in Figures 5a-d, we need to account for the payment of the fixed charge by all households and, for those households falling in the upper block, we need to include in the calculation the benefit of getting the units included in the lower block at a lower price.

The full set of results is shown in Tables 9 and 10. We find that the percentage of subsidies received by households in the poorest quintile, the average subsidy per household, and the deadweight loss are similar to the scenarios presented in Tables 7 and 8 in which households respond to average prices.

Under the 100% cost recovery assumption, the deadweight loss is small, in the range US$0-2 per household, and the following relationships hold whether households respond to average or marginal prices: i) for a given lifeline block, an increase in the fixed charge always decreases deadweight loss; and ii) for a given fixed charge, an increase in the size of the lifeline block always increases the deadweight loss. Thus, in the 100% cost recovery case, a large fixed charge combined to a small lifeline block produces the smallest deadweight loss. This is because a small lifeline block and a large fixed charge produce an average price and a marginal price that are quite close to the UP tariff of US$5 per $m^3$. Figure 6 provides a graphic illustration under a 100% cost recovery assumption: SC1 is the IBT-0-10 (US$0 fixed charge and $10m^3$ lifeline block) while SC15 is the IBT-15-5 (US$15 fixed charge and $5m^3$ lifeline block). Both the average and marginal prices under the IBT-15-5 are close to US$5 so the change in prices when moving from UP to IBT is very small and hence the loss in welfare is small. However, this is the worst scenario for households in the poorest quintile because they receive the lowest proportion of subsidies under this particular tariff structure (15% of the total subsidies under a +0.1 correlation between water use and income, and less than 1% of the total subsidies under a +0.8 correlation).

Under the 50% cost recovery assumption, the average deadweight loss varies from US$3 to US$6 per household under the assumption that households respond to marginal prices, with larger deadweight losses occurring with a US$15 fixed charge. The deadweight loss was around US$4.5 per household for all scenarios when households were assumed to respond to average prices.

### *6.2. Does the utility operate under constant returns to scale?*

If the utility operated under increasing returns to scale, then the average cost of production would be higher than the marginal cost. For example, if we assumed that the marginal cost is still US$5 per $m^3$ but that the average cost is a specified amount above that, this would have implications on the calculation of the subsidies distributed to each quintile (but not on the proportion of total subsidies received by each quintile). The calculation of the deadweight loss would be unchanged.

One could refine the calculations further by specifying a cost function that describes the relationship between the cost and the quantity of water produced more precisely. One would then adjust the marginal cost and average cost depending on the total amount of water produced.

### *6.3. Are additional criteria needed?*

Another extension of our modeling would be to add criteria. An obvious candidate for non-economists would be “water conservation.” This would require reporting the total water use under the different scenarios. The total water use varies across scenarios because the price elasticity of demand is assumed to be negative. For example, under the reference (UP) case, the total water sold to the 5000 households amounts to about 115,000 $m^3$. Scenarios with IBTs with a zero fixed charge under 100% cost recovery assumption have the largest differences in total water use compared to the reference case (about 15% lower).

## 7. Discussion

More careful modeling of the consequences of water tariff reforms is needed to counter the global conventional wisdom that IBTs are a sound, effective approach for balancing financial self-sufficiency, equity, and economic efficiency criteria. The results presented in this paper show that for a given level of cost recovery, IBTs can lead to societal losses while doing little to increase equity. Our results also suggest that the trade-offs between the criteria of equity and economic efficiency in the design of water tariffs are different to those generally assumed by water utility managers and policy makers. Water tariff consultants spend much time and effort tinkering with the details of new IBT designs without recognizing how little such changes matter to the effective targeting of subsidies to poor households in most circumstances. These findings hold whether households respond to the average or the marginal price.

In the past poorly performing water tariffs have not been perceived to be a large societal problem, but this is changing with growing water scarcity and climate change. Our results show how the performance of alternative tariff designs depends on a set of assumptions that require empirical verification in a specific local setting. We emphasize that the generalizability of our findings to specific utilities in both industrialized and developing countries depends on the analyst finding estimates of the parameters used in the simulation model that can accurately portray local conditions. It is especially important to obtain accurate estimates of the correlation between household water use and income, the relationship between average and marginal costs, the price (average or marginal) to which households are responding, and the target level of cost recovery.

*Acknowledgments*: We would like to thank the following individuals for helpful comments on previous drafts of this paper: John Boland, Clarissa Brocklehurt, Joe Cook, Jerson Kelmon, Lewis Kornhauser, Jack Knetsch, Donald Lauria, Duncan Thomas, and Mike Young.

## References

Arbués, F., Barberán, R., 2012. Tariffs for urban water services in Spain: household size and equity. *International Journal of Water Resources Development* 28 (1): 123–140.

Boardman, A., Greenberg, D., Vining, A., Weimer, D., 2011. *Cost-Benefit Analysis: Concepts and Practice*. Fourth Edition. Prentice Hall.

Boland, J., Whittington, D., 2000. The political economy of water tariff design in developing countries: increasing block tariffs versus uniform price with rebate. In The Political Economy of Water Pricing Reforms, edited by Ariel Dinar. New York: Oxford University Press.

Borenstein, S., 2012. The redistributional impact of nonlinear electricity pricing. *American Economic Journal: Economic Policy* 4(3): 56–90.

Briand, A., Nauges, C., Strand, J., Travers, M., 2010. The impact of tap connection on water use: the case of household water consumption in Dakar, Senegal. *Environment and Development Economics* 15(1): 107–126.

Correia, R., Monteiro, H., Roseta Palma, C., Martins, R., 2015. Do you know how much you pay for water? Mimeo. ISCTE, Lisbon, Portugal.

Danilenko, A., van den Berg, C., Macheve, B., Moffitt, L.J., 2014. The IBNET Water Supply and Sanitation Blue Book 2014: The International Benchmarking Network for Water and Sanitation Utilities Databook. World Bank Group, Washington, DC. © World Bank. https://openknowledge.worldbank.org/handle/10986/19811 License: CC BY 3.0 IGO.

Fuente, D., Gatua, J.G., Ikiara, M. Kabubo-Mariara, J., Mwaura, M., Whittington, D., 2016. Water and sanitation service delivery, pricing, and the poor: An empirical analysis of subsidy incidence in Nairobi, Kenya. *Water Resources Research,* doi: 10.1002/2015WR018375.

Grafton, R.Q., Ward M.B., To, H., and T. Kompas, 2011. Determinants of residential water consumption: Evidence and analysis from a 10-country household survey. *Water Resources Research* Vol. 47, W08537, doi:10.1029/2010WR009685.

Hausman, J.A., 1981. Exact consumer's surplus and deadweight loss. *American Economic Review* 71(4): 662–676.

Ito, K., 2014. Do consumers respond to marginal or average price? Evidence from nonlinear electricity pricing. *American Economic Review* 104(2): 537–63.

Johnson, M.E., Tenenbein, A., 1981. A bivariate distribution family with specified marginals. *Journal of the American Statistical Association* 76(373): 198–201.

Nauges, C., van den Berg, C., 2009. Demand for piped and non-piped water supply services: evidence from southwest Sri Lanka. *Environmental and Resource Economics* 42(4): 535–549.

Nauges, C., Whittington, D., 2010. Estimation of water demand in developing countries: an overview. *The World Bank Research Observer* 25(2): 263–294.

OECD. 2011. *Greening Household Behaviour: The Role of Public Policy*, OECD. Paris.

Renzetti, S., Dupont, D.P., Chitsinde, T., 2015. An empirical examination of the distributional impacts of water pricing reforms. *Utilities Policy* 34: 63–69.

Reynaud, A., 2016. Assessing the impact of full cost recovery of water services on European households. *Water Resources and Economics* 14: 65–78.

Saal, D.S., Arocena, P., Maziotis, A., Triebs, T., 2013. Scale and scope economies and the efficient vertical and horizontal configuration of the water industry: A survey of the literature. *Review of Network Economics* 12(1): 93–129.

Strand, J., Walker, I., 2003. The pricing and allocation of water in Central America: analysis of metered and coping water demand in 17 Central American cities. Report to the Inter-American Development Bank, University of Oslo/ESA Consultores.

Szabo, A., 2015. The value of free water: analysing South Africa's free basic water policy. *Econometrica* 83(5): 1913-1961.

Whittington, D., 1992. Possible Adverse Effects of Increasing Block Water Tariffs in Developing Countries. *Economic Development and Cultural Change*. 41(1): 75-87.

Whittington, D., Nauges, C., Fuente, D., Wu, X., 2015. A diagnostic tool for estimating the incidence of subsidies delivered by water utilities in low- and medium-income countries, with illustrative simulations. *Utilities Policy* 34: 70-81.

Table 1 - Empirical evidence on the correlation between water use and income

| Location | Study in which dataset is described | Sample size | Spearman's $\rho$ |
|---|---|---|---|
| *OECD countries* | | | |
| Australia | Grafton et al. (2011) | 154 | 0.12 (n.s.) |
| Canada | Grafton et al. (2011) | 47 | 0.27 |
| France | Grafton et al. (2011) | 326 | 0.15 |
| Italy | Grafton et al. (2011) | 249 | -0.05 (n.s.) |
| Korea | Grafton et al. (2011) | 109 | -0.10 (n.s.) |
| Netherlands | Grafton et al. (2011) | 191 | 0.12 |
| Norway | Grafton et al. (2011) | 57 | 0.32 |
| Portugal | Correia et al. (2015) | 1575 | 0.18 |
| Sweden | Grafton et al. (2011) | 88 | 0.05 (n.s.) |
| | | | |
| *Developing countries* | | | |
| Sri Lanka (3 cities) | Nauges and van den Berg (2009) | 590 | 0.28 |
| El Salvador (3 cities) | Strand and Walker (2003) | 398 | 0.13 |
| Dakar, Senegal | Briand et al. (2010) | 112 | 0.24 |
| Nairobi, Kenya | Fuente et al. (2015) | 648 | 0.34 |

Note: n.s. = non-significant at 95%.

Table 2 - Descriptive statistics on household water use and income (source: 2008 OECD EPIC survey)

| | Nb. of obs. | Mean water use ($m^3$/month) | Median water use ($m^3$/month) | Mean income (US$/month) |
|---|---|---|---|---|
| Canada | 52 | 41 | 16 | 4746 |
| Netherlands | 198 | 15 | 9 | 3512 |
| France | 338 | 11 | 8 | 3994 |
| Italy | 256 | 34 | 17 | 3804 |
| Sweden | 91 | 18 | 11 | 3518 |
| Norway | 57 | 15 | 12 | 7199 |
| Australia | 163 | 37 | 16 | 4316 |
| Korea | 111 | 42 | 18 | 3051 |

Table 3 - Nine alternative IBT tariff designs + status quo UP tariff

| Tariff Code | Type of tariff | FC (US$/mo.) | LLB ($m^3$/mo.) |
|---|---|---|---|
| UP-0 | UP | 0 | 0 |
| IBT-0-5 | IBT | 0 | 5 |
| IBT-0-10 | IBT | 0 | 10 |
| IBT-0-15 | IBT | 0 | 15 |
| IBT-10-5 | IBT | 10 | 5 |
| IBT-10-10 | IBT | 10 | 10 |
| IBT-10-15 | IBT | 10 | 15 |
| IBT-15-5 | IBT | 15 | 5 |
| IBT-15-10 | IBT | 15 | 10 |
| IBT-15-15 | IBT | 15 | 15 |

Notes: UP = Uniform Pricing, IBT = Increasing Block Tariff, FC =fixed charge, LLB = lifeline block

Table 4 - Model assumptions

| **Assumptions that are varied …** | **Parameter value** |
|---|---|
| Correlation between household income and water use | +0.1, +0.8 |
| Percent cost recovery | 50%, 100% |
| Price to which households respond | Average, marginal |
| Size of lifeline block | 5 $m^3$, 10 $m^3$, 15 $m^3$ |
| Size of fixed charge | 0, US$10, US$15 |
| | |
| **Assumptions that are not varied …** | |
| All households have metered, piped connections | |
| Status quo tariff structure | Uniform volumetric tariff with price set equal to marginal cost = average cost |
| Average cost of water and wastewater services | US$5 per $m^3$ |
| Price elasticity of demand | -0.2 |
| Income elasticity | 0.0 |
| IBT has two blocks | |
| Relationship between volumetric price in the first block ($P_1$) and price in the second block ($P_2$) | $P_1 = ½ P_2$ |
| Lower limit on household water use | 5 $m^3$ |
| Household demand function for water | log-log |

Table 5 – Results for benchmark case: 50% cost recovery; correlation between water use and income = 0.1; IBT no fixed charge; LLB=10$m^3$/mo.

| *By income quintile (Q1 to Q5) and in total* | **Q1** | **Q2** | **Q3** | **Q4** | **Q5** | **Total** |
|---|---|---|---|---|---|---|
| **In total** | | | | | | |
| Total number of households | 1000 | 1000 | 1000 | 1000 | 1000 | 5000 |
| Total water use (m3) | 20,060 | 21,639 | 22,848 | 24,005 | 25,867 | 114,419 |
| Total revenue from bills (US$) | 48,717 | 53,453 | 57,082 | 60,569 | 66,223 | 286,043 |
| Total cost (US$) | 100,300 | 108,194 | 114,240 | 120,025 | 129,336 | 572,095 |
| Total revenue - total cost (US$) | -51,583 | -54,741 | -57,158 | -59,456 | -63,113 | -286,051 |
| Total change in surplus with respect to UP (US$) | 47,249 | 50,264 | 52,571 | 54,766 | 58,263 | 263,113 |
| Cost recovery (%) | 49 | 49 | 50 | 50 | 51 | 50 |
| **For households receiving subsidies (price is below cost)** | | | | | | |
| Number of hh receiving subsidies | 1000 | 1000 | 1000 | 1000 | 1000 | 5000 |
| Total subsidies distributed (US$) | 51583 | 54741 | 57158 | 59456 | 63113 | 286051 |
| Total subsidies distributed (%) | 18 | 19 | 20 | 21 | 22 | 100 |
| Total change in surplus with respect to UP (US$) | 47,249 | 50,264 | 52,571 | 54,766 | 58,263 | 263,113 |
| Total water use (m3) | 20,060 | 21,639 | 22,848 | 24,005 | 25,867 | 114,419 |
| Total revenue from bills (US$) | 48,717 | 53,453 | 57,082 | 60,569 | 66,223 | 286,043 |
| Average subsidy per household (US$) | 51.6 | 54.7 | 57.2 | 59.5 | 63.1 | 57.2 |
| Average subsidy per m3 (US$) | 2.6 | 2.5 | 2.5 | 2.5 | 2.4 | 2.5 |
| Average water bill per household (US$) | 49 | 53 | 57 | 61 | 66 | 57 |
| Average water use per household (m3) | 20 | 22 | 23 | 24 | 26 | 23 |
| **For households making payments (price is above cost)** | | | | | | |
| Number of hh making payments | 0 | 0 | 0 | 0 | 0 | 0 |
| Total payments made (US$) | 0 | 0 | 0 | 0 | 0 | 0 |
| Total payments made (%) | 0 | 0 | 0 | 0 | 0 | 0 |
| Total change in surplus with respect to UP (US$) | 0 | 0 | 0 | 0 | 0 | 0 |
| Total water use (m3) | 0 | 0 | 0 | 0 | 0 | 0 |
| Total revenue from bills (US$) | 0 | 0 | 0 | 0 | 0 | 0 |
| Average payment per household (US$) | 0 | 0 | 0 | 0 | 0 | 0 |
| Average payment per m3 (US$) | 0 | 0 | 0 | 0 | 0 | 0 |
| Average water bill per household (US$) | 0 | 0 | 0 | 0 | 0 | 0 |

Table 6 – Scenario 1: 100% cost recovery; correlation between water use and income = 0.1; IBT no fixed charge; LLB = 10m³/mo.

| *By income quintile (Q1 to Q5) and in total* | **Q1** | **Q2** | **Q3** | **Q4** | **Q5** | **Total** |
|---|---|---|---|---|---|---|
| **In total** | | | | | | |
| Total number of households | 1000 | 1000 | 1000 | 1000 | 1000 | 5000 |
| Total water use (m3) | 18,266 | 19,696 | 20,468 | 21,712 | 23,400 | 103,543 |
| Total revenue from bills (US$) | 88,686 | 97,320 | 102,017 | 109,670 | 120,018 | 517,711 |
| Total cost (US$) | 91,331 | 98,480 | 102,342 | 108,561 | 117,000 | 517,714 |
| Total revenue - total cost (US$) | -2645 | -1160 | -325 | 1109 | 3018 | -3 |
| Total change in surplus with respect to UP (US$) | 2232 | 748 | -89 | -1528 | -3443 | -2080 |
| Cost recovery (%) | 97 | 99 | 100 | 101 | 103 | 100 |
| **For households receiving subsidies (price is below cost)** | | | | | | |
| Number of hh receiving subsidies | 770 | 742 | 727 | 703 | 673 | 3614 |
| Total subsidies distributed (US$) | 8783 | 8439 | 8256 | 7935 | 7553 | 40,965 |
| Total subsidies distributed (%) | 21 | 21 | 20 | 19 | 18 | 100 |
| Total change in surplus with respect to UP (US$) | 8459 | 8133 | 7960 | 7653 | 7290 | 39,495 |
| Total water use (m3) | 8414 | 8354 | 8309 | 8188 | 8043 | 41,308 |
| Total revenue from bills (US$) | 33,287 | 33,333 | 33,289 | 33,004 | 32,663 | 165,576 |
| Average subsidy per household (US$) | 11.4 | 11.4 | 11.4 | 11.3 | 11.2 | 11.3 |
| Average subsidy per m3 (US$) | 1.0 | 1.0 | 1.0 | 1.0 | 0.9 | 1.0 |
| Average water bill per household (US$) | 43 | 45 | 46 | 47 | 49 | 46 |
| Average water use per household (m3) | 11 | 11 | 11 | 12 | 12 | 11 |
| **For households making payments (price is above cost)** | | | | | | |
| Number of hh making payments | 230 | 258 | 273 | 297 | 327 | 1386 |
| Total payments made (US$) | 6137 | 7278 | 7931 | 9044 | 10,571 | 40,962 |
| Total payments made (%) | 15 | 18 | 19 | 22 | 26 | 100 |
| Total change in surplus with respect to UP (US$) | -6227 | -7386 | -8049 | -9181 | -10,733 | -41,575 |
| Total water use (m3) | 9852 | 11,342 | 12,159 | 13,524 | 15,357 | 62,235 |
| Total revenue from bills (US$) | 55,399 | 63,987 | 68,728 | 76,666 | 87,355 | 352,135 |
| Average payment per household (US$) | 26.6 | 28.2 | 29.1 | 30.5 | 32.3 | 29.6 |
| Average payment per m3 (US$) | 0.6 | 0.6 | 0.7 | 0.7 | 0.7 | 0.7 |
| Average water bill per household (US$) | 241 | 248 | 252 | 258 | 267 | 254 |
| Average water use per household (m3) | 43 | 44 | 45 | 46 | 47 | 45 |

Table 7 – Alternatives-by-criteria decision matrix (correlation between household income and water use = +0.1); household responds to average price

| **Criteria** | IBT-0-5* | IBT-0-10 | IBT-0-15 | IBT-10-5 | IBT-10-10 | IBT-10-15 | IBT-15-5 | IBT-15-10 | IBT-15-15 |
|---|---|---|---|---|---|---|---|---|---|
| **Cost recovery** | 50% | 50% | 50% | 50% | 50% | 50% | 50% | 50% | 50% |
| **Equity** | | | | | | | | | |
| % of subsidies to poorest quintile | 18% | 18% | 18% | 17% | 18% | 18% | 17% | 17% | 17% |
| Average monthly subsidy in poorest quintile | US$51 | US$52 | US$52 | US$50 | US$50 | US$50 | US$49 | US$49 | US$49 |
| **Economic efficiency (deadweight loss)** | -US$21,810<br>(US$4.4/hh) | -US$22,938<br>(US$4.6/hh) | -US$23,546<br>(US$4.7/hh) | -US$21,276<br>(US$4.3/hh) | -US$21,133<br>(US$4.2/hh) | -US$21,419<br>(US$4.3/hh) | -US$22,216<br>(US$4.4/hh) | -US$21,827<br>(US$4.4/hh) | -US$21,903<br>(US$4.4/hh) |
| **Cost recovery** | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% |
| **Equity** | | | | | | | | | |
| % of subsidies to poorest quintile | 22% | 21% | 21% | 22% | 21% | 20% | 15% | 20% | 19% |
| Average monthly subsidy in poorest quintile | US$7 | US$11 | US$13 | US$2 | US$5 | US$9 | US$3 | US$5 | US$8 |
| **Economic efficiency (deadweight loss)** | -US$920<br>(US$0.2/hh) | -US$2080<br>(US$0.4/hh) | -US$2596<br>(US$0.5/hh) | -US$197<br>(US$0.0/hh) | -US$519<br>(US$0.1/hh) | -US$951<br>(US$0.2/hh) | -US$26<br>(US$0.0/hh) | -US$272<br>(US$0.1/hh) | -US$646<br>(US$0.1/hh) |

* IBT-0-5 stands for an IBT design with a US$0 fixed charge and a 5m$^3$ lifeline block.

Table 8 – Alternatives-by-criteria decision matrix (correlation between household income and water use = +0.8); household responds to average price

| **Criteria** | IBT-0-5* | IBT-0-10 | IBT-0-15 | IBT-10-5 | IBT-10-10 | IBT-10-15 | IBT-15-5 | IBT-15-10 | IBT-15-15 |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |
| **Cost recovery** | 50% | 50% | 50% | 50% | 50% | 50% | 50% | 50% | 50% |
| **Equity** | | | | | | | | | |
| % of subsidies to poorest quintile | 8% | 9% | 9% | 5% | 6% | 6% | 4% | 4% | 4% |
| Average monthly subsidy in poorest quintile | US$24 | US$25 | US$25 | US$16 | US$17 | US$16 | US$11 | US$12 | US$12 |
| **Economic efficiency (deadweight loss)** | -US$21,775<br>(US$4.4/hh) | -US$22,913<br>(US$4.6/hh) | -US$23,540<br>(US$4.7/hh) | -US$21,250<br>(US$4.3/hh) | -US$21,229<br>(US$4.2/hh) | -US$21,419<br>(US$4.3/hh) | -US$22,202<br>(US$4.4/hh) | -US$21,794<br>(US$4.4/hh) | -US$21,903<br>(US$4.4/hh) |
| | | | | | | | | | |
| **Cost recovery** | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% |
| **Equity** | | | | | | | | | |
| % of subsidies to poorest quintile | 39% | 28% | 21% | 40% | 16% | 9% | <1% | 11% | 7% |
| Average monthly subsidy in poorest quintile | US$9 | US$12 | US$10 | US$2 | US$3 | US$6 | US$1 | US$5 | US$6 |
| **Economic efficiency (deadweight loss)** | -US$870<br>(US$0.2/hh) | -US$2102<br>(US$0.4/hh) | -US$2658<br>(US$0.5/hh) | -US$204<br>(US$0.0/hh) | -US$454<br>(US$0.1/hh) | -US$970<br>(US$0.2/hh) | -US$34<br>(US$0.0/hh) | -US$233<br>(US$0.0/hh) | -US$626<br>(US$0.1/hh) |

* IBT-0-5 stands for an IBT design with a US$0 fixed charge and a 5m$^3$ lifeline block.

Table 9 – Alternatives-by-criteria decision matrix (correlation between household income and water use = +0.1); household responds to marginal price

| **Criteria** | IBT-0-5* | IBT-0-10 | IBT-0-15 | IBT-10-5 | IBT-10-10 | IBT-10-15 | IBT-15-5 | IBT-15-10 | IBT-15-15 |
|---|---|---|---|---|---|---|---|---|---|
| **Cost recovery** | 50% | 50% | 50% | 50% | 50% | 50% | 50% | 50% | 50% |
| **Equity** | | | | | | | | | |
| % of subsidies to poorest quintile | 18% | 18% | 18% | 17% | 18% | 18% | 17% | 17% | 17% |
| Average monthly subsidy in poorest quintile | US$51 | US$51 | US$51 | US$50 | US$51 | US$51 | US$50 | US$51 | US$50 |
| **Economic efficiency (deadweight loss)** | -US$15,046<br>(US$3.0/hh) | -US$14,051<br>(US$2.8/hh) | -US$13,965<br>(US$2.8/hh) | -US$25,340<br>(US$5.1/hh) | -US$23,826<br>(US$4.8/hh) | -US$23,359<br>(US$4.7/hh) | -US$32,101<br>(US$6.4/hh) | -US$30,233<br>(US$6.0/hh) | US$29,454<br>(US$5.9/hh) |
| **Cost recovery** | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% |
| **Equity** | | | | | | | | | |
| % of subsidies to poorest quintile | 22% | 21% | 21% | 22% | 21% | 20% | 15% | 20% | 19% |
| Average monthly subsidy in poorest quintile | US$7 | US$12 | US$13 | US$2 | US$6 | US$9 | US$3 | US$5 | US$9 |
| **Economic efficiency (deadweight loss)** | -US$959<br>(US$0.2/hh) | -US$4101<br>(US$0.8/hh) | -US$6468<br>(US$1.3/hh) | -US$168<br>(US$0.0/hh) | -US$2441<br>(US$0.5/hh) | -US$4469<br>(US$0.9/hh) | US$193<br>(US$0.0/hh) | -US$2046<br>(US$0.4/hh) | -US$3886<br>(US$0.8/hh) |

* IBT-0-5 stands for an IBT design with a US$0 fixed charge and a $5m^3$ lifeline block.

Table 10 – Alternatives-by-criteria decision matrix (correlation between household income and water use = +0.8); household responds to marginal price

| **Criteria** | IBT-0-5* | IBT-0-10 | IBT-0-15 | IBT-10-5 | IBT-10-10 | IBT-10-15 | IBT-15-5 | IBT-15-10 | IBT-15-15 |
|---|---|---|---|---|---|---|---|---|---|
| **Cost recovery** | 50% | 50% | 50% | 50% | 50% | 50% | 50% | 50% | 50% |
| **Equity** | | | | | | | | | |
| % of subsidies to poorest quintile | 8% | 9% | 9% | 6% | 6% | 6% | 4% | 5% | 5% |
| Average subsidy in poorest quintile | US$24 | US$25 | US$25 | US$16 | US$18 | US$18 | US$13 | US$14 | US$14 |
| **Economic efficiency (deadweight loss)** | -US$15,045<br>(US$3.0/hh) | -US$14,051<br>(US$2.8/hh) | -US$13,973<br>(US$2.8/hh) | -US$25,331<br>(US$5.1/hh) | -US$23,823<br>(US$4.8/hh) | -US$23,372<br>(US$4.7/hh) | -US$32,008<br>(US$6.4/hh) | -US$30,227<br>(US$6.0/hh) | -US$29,453<br>(US$5.9/hh) |
| | | | | | | | | | |
| **Cost recovery** | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% |
| **Equity** | | | | | | | | | |
| % of subsidies to poorest quintile | 39% | 27% | 20% | 39% | 18% | 9% | <1% | 12% | 7% |
| Average subsidy in poorest quintile | US$10 | US$11 | US$10 | US$2 | US$4 | US$6 | US$1 | US$5 | US$6 |
| **Economic efficiency (deadweight loss)** | -US$924<br>(US$0.2/hh) | -US$4098<br>(US$0.8/hh) | -US$6488<br>(US$1.3/hh) | -US$159<br>(US$0.0/hh) | -US$2416<br>(US$0.5/hh) | -US$4484<br>(US$0.9/hh) | US$226<br>(US$0.0/hh) | -US$2067<br>(US$0.4/hh) | -US$3886<br>(US$0.8/hh) |

IBT-0-5 stands for an IBT design with a US$0 fixed charge and a 5m$^3$ lifeline block.

Figure 1 - Average water price (US\$/m$^3$) vs. monthly water use (m$^3$) under three IBT tariffs with US\$0 fixed charge (FC) and three sizes of the lifeline block (5m$^3$, 10m$^3$, and 15m$^3$ per month)

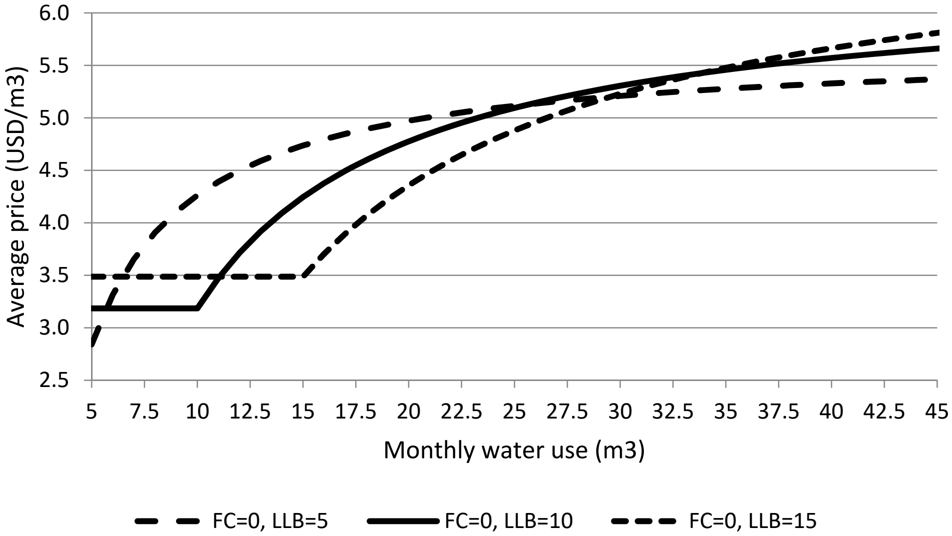


Figure 2 - Average water price (US\$/m$^3$) as a function of monthly water use (m$^3$) under three IBT tariffs with non-zero fixed charge (FC) and two sizes of the lifeline block (LLB): 5m$^3$ and 10m$^3$ per month

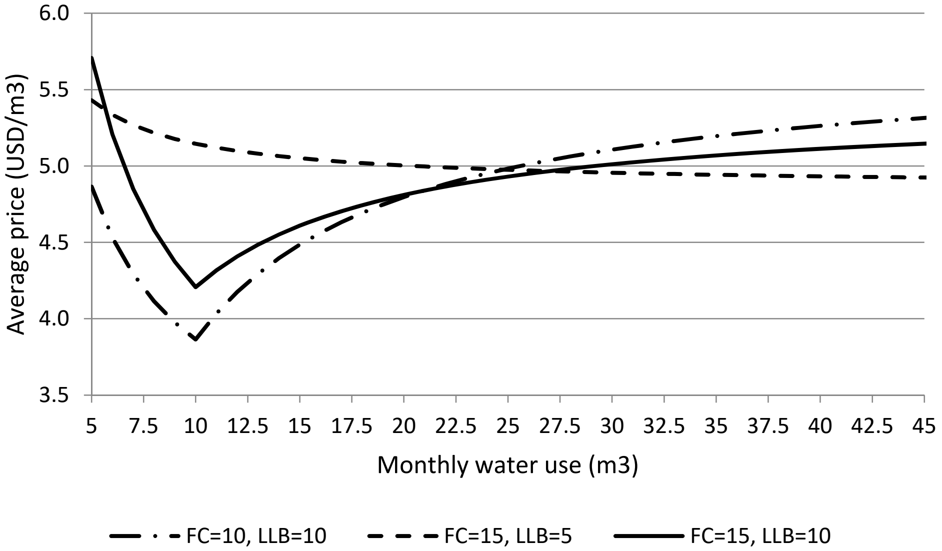


Figure 3 – Distribution of subsidies across quintiles (Q1 to Q5) under four different scenarios (IBT with US$0 fixed charge and 10m³ lifeline block)

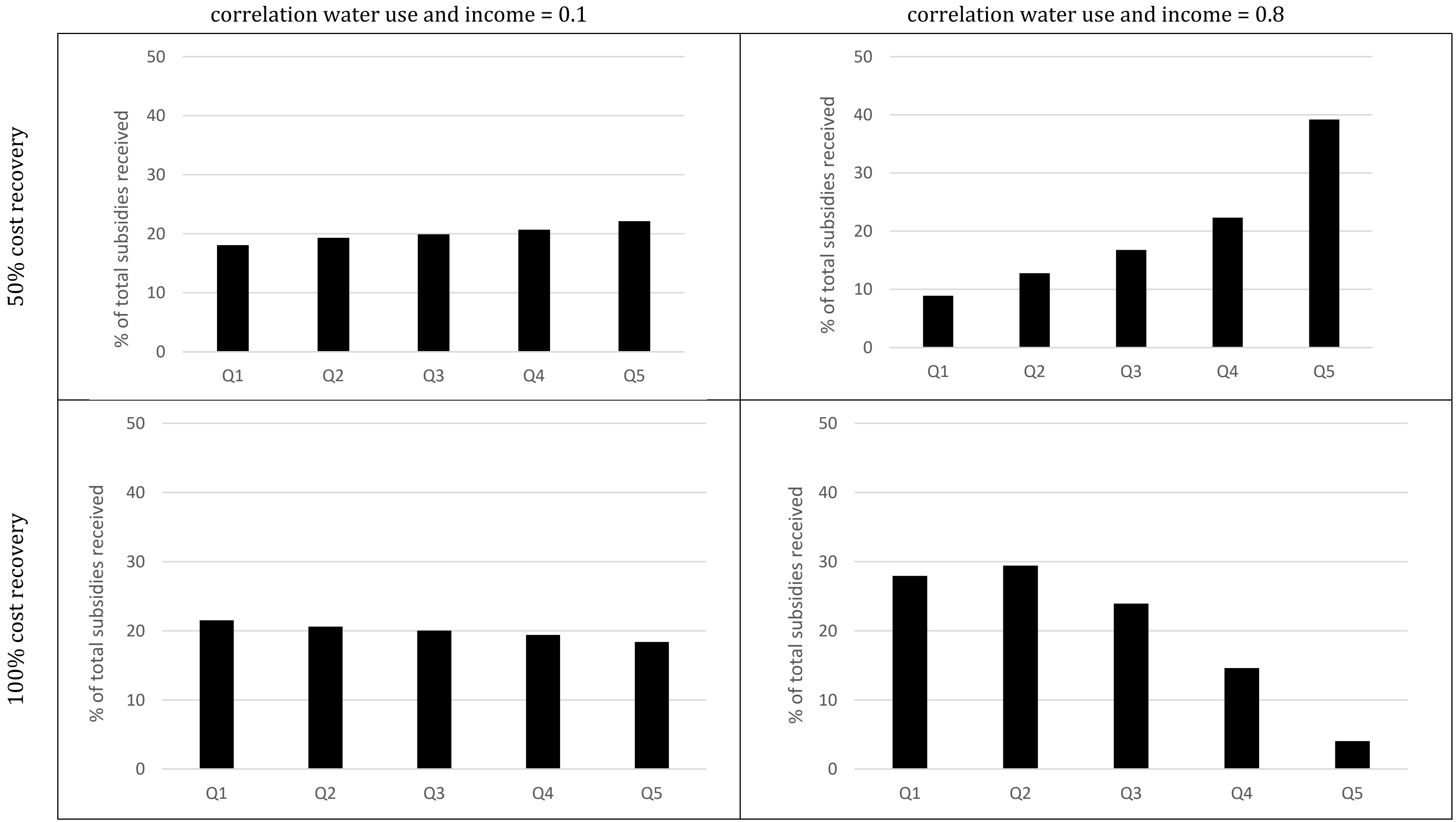
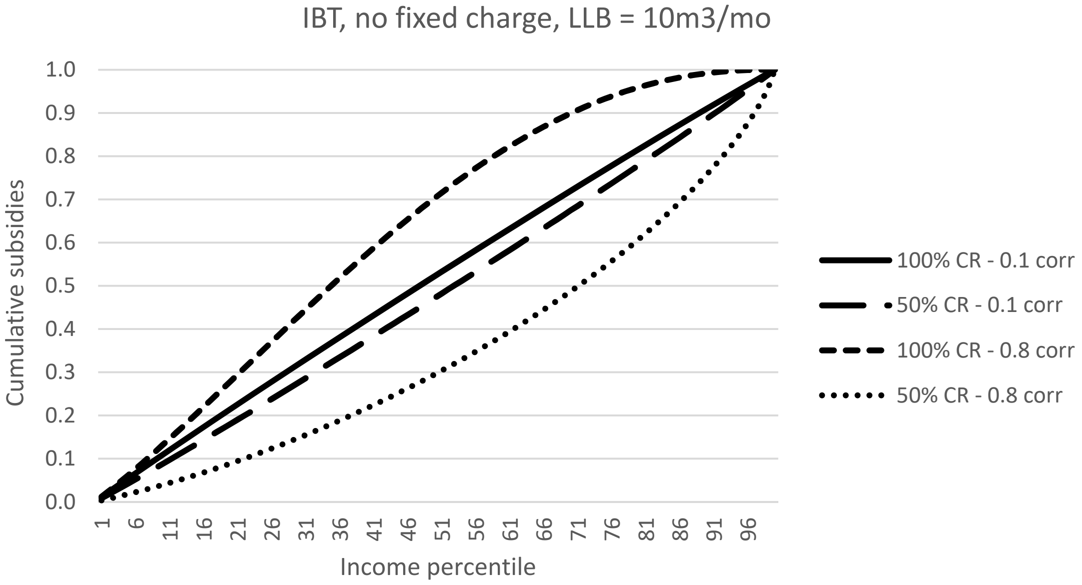


Figure 4 – Cumulative distribution of subsidies vs. household income percentile; two levels of cost recovery (50%, 100%) and two levels of correlation (+0.1, +0.8)



Figures 5a-d – Calculating the consumer surplus of a shift from UP to IBT tariff (4 cases)

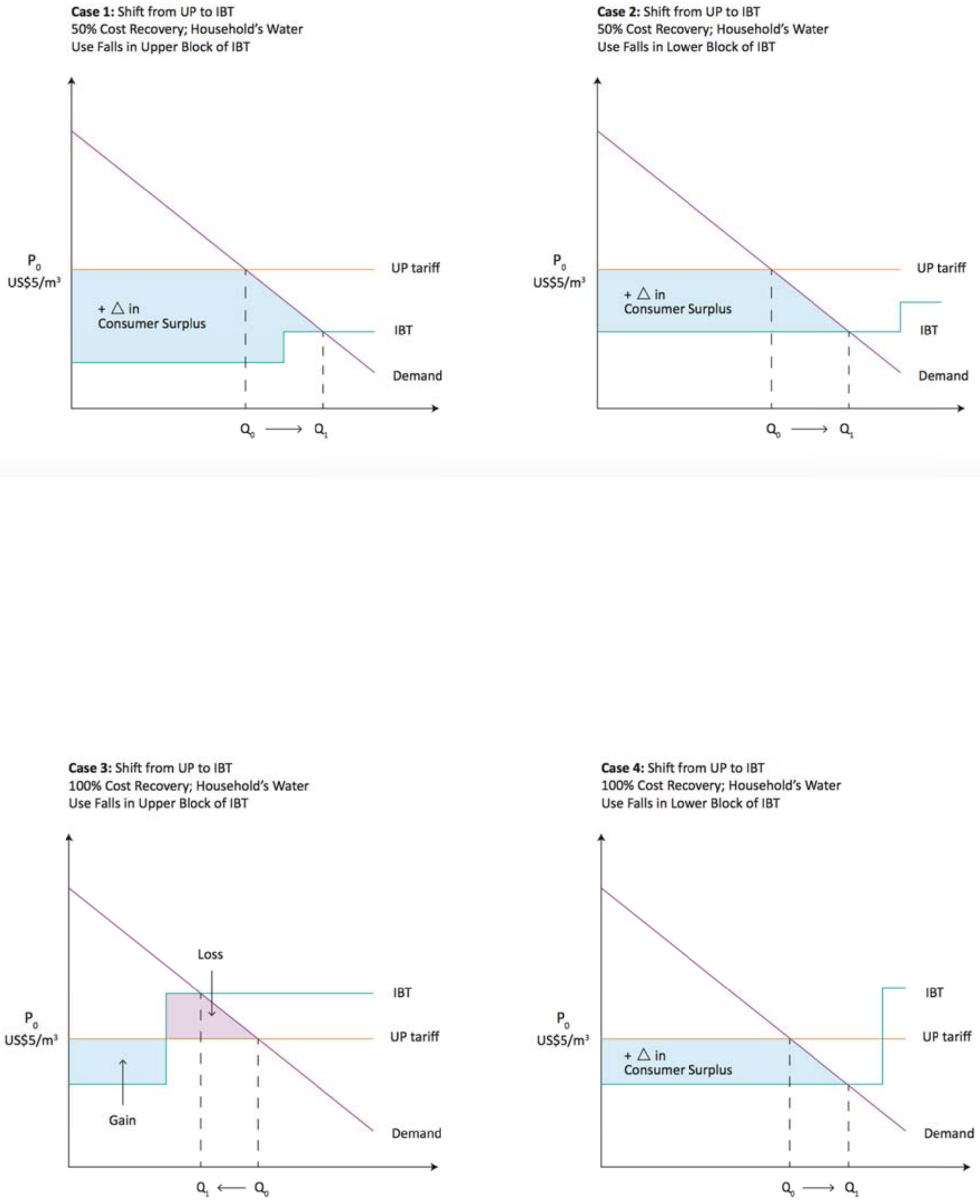
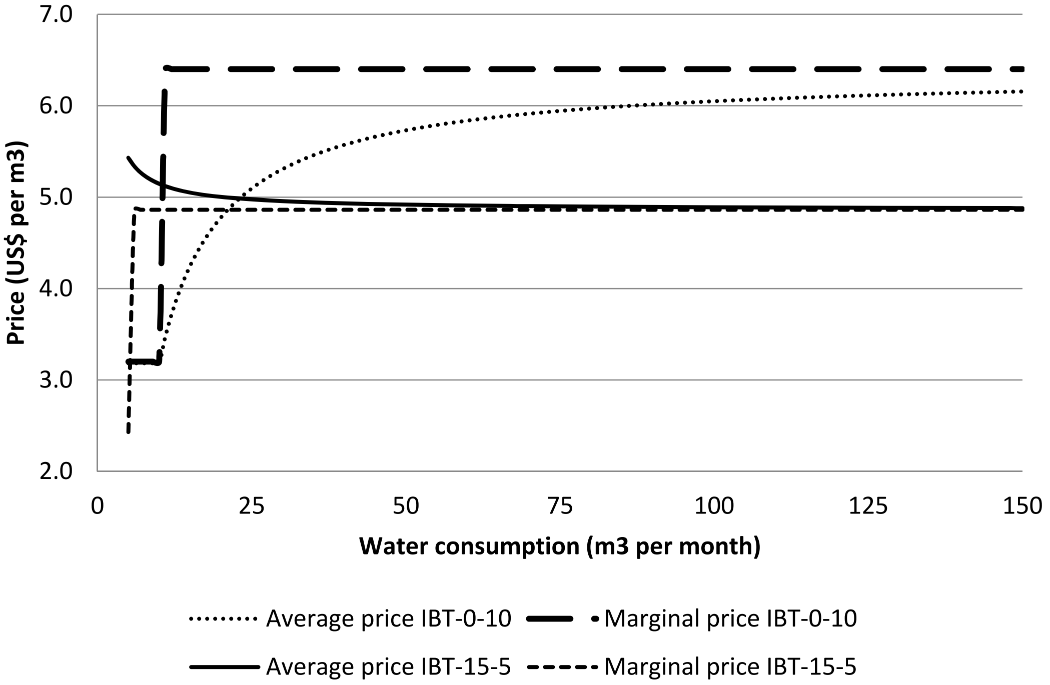


Figure 6 - Average and marginal prices under IBT-0-10 (US$0 fixed charge and 10m³ lifeline block) and IBT-15-5 (US$15 fixed charge and 5m³ lifeline block), 100% cost recovery



## Appendix A: Description of 36 scenarios